Document made available under the Patent Cooperation Treaty (PCT)

International application number: PCT/CA05/000339

International filing date: 03 March 2005 (03.03.2005)

Document type: Certified copy of priority document

Document details: Country/Office: US
Number: 60/549,172
Filing date: 03 March 2004 (03.03.2004)

Date of receipt at the International Bureau: 15 June 2005 (15.06.2005)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)

PA 1295527

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE

United States Patent and Trademark Office

March 17, 2005

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THE UNITED STATES PATENT AND TRADEMARK OFFICE OF THOSE PAPERS OF THE BELOW IDENTIFIED PATENT APPLICATION THAT MET THE REQUIREMENTS TO BE GRANTED A FILING DATE UNDER 35 USC 111.

APPLICATION NUMBER: *60/549,172*
FILING DATE: *March 03, 2004*

PCT/CA05/00339

By Authority of the
COMMISSIONER OF PATENTS AND TRADEMARKS

Trudie Wallace
TRUDIE WALLACE
Certifying Officer

16698 U.S. PTO

PTO/SB/16 (01-04)
Approved for use through 07/31/2006. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No.

22387 U.S. PTO
60/549172
030304

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Robert	TREMBLAY	Montréal, Québec, CANADA

Additional inventors are being named on the 1 *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

PRE-TENSIONED SELF-CENTERING ENERGY DISSIPATIVE BRACE APPARATUS

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

☐ Customer Number:

OR

☑ Firm or Individual Name	BROUILLETTE KOSIE PRINCE				
Address	1100 René-Lévesque Blvd. West, 25th Floor				
Address					
City	Montréal	State	Québec	Zip	H3B 5C9
Country	CANADA	Telephone	514-397-6942	Fax	514-397-8515

ENCLOSED APPLICATION PARTS ***(check all that apply)***

☑ Specification *Number of Pages* 24

☑ Drawing(s) *Number of Sheets* 8

☐ Application Data Sheet. See 37 CFR 1.76

☐ CD(s), Number

☐ Other (specify)

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☑ Applicant claims small entity status. See 37 CFR 1.27.

☐ A check or money order is enclosed to cover the filing fees.

☐ The Director is herby authorized to charge filing fees or credit any overpayment to Deposit Account Number:

☑ Payment by credit card. Form PTO-2038 is attached.

FILING FEE Amount ($): $80.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☑ No.

☐ Yes, the name of the U.S. Government agency and the Government contract number are:

Respectfully submitted,

SIGNATURE Ronald S. Kosie

TYPED or PRINTED NAME Ronald S. KOSIE

TELEPHONE 514-397-6942

Date March 2, 2004

REGISTRATION NO. 28,814
(if appropriate)
Docket Number: 08400-022

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

This collection of information is required by 37 CFR 1.51. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 8 hours to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Mail Stop Provisional Application, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

PROVISIONAL APPLICATION COVER SHEET
Additional Page

PTO/SB/16 (08-03)
Approved for use through 07/31/2006. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Docket Number	08400-022

INVENTOR(S)/APPLICANT(S)

Given Name (first and middle [if any])	Family or Surname	Residence (City and either State or Foreign Country)
Constantin	CHRISTOPOULOS	Toronto, Ontario, CANADA

[Page 2 of 2]

Number 2 of 2

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

TITLE OF THE INVENTION

Pre-Tensioned Self-Centering Energy Dissipative Brace Apparatus

FIELD OF THE INVENTION

[0001] The present invention generally relates to an energy dissipative brace apparatus with self-centering properties. More specifically, the present invention is concerned with a brace apparatus for installation in structures which may be subjected to extreme loading conditions.

BACKGROUND OF THE INVENTION

[0002] Although the design of structures under normal loading conditions aims at meeting serviceability requirements by providing strength, stiffness and stability, it has been recognized in the past thirty years that to effectively and safely resist extreme loading conditions such as earthquakes and blast loads, a fundamentally different approach must be used. It is economically unfeasible as well as being potentially unsafe to design structures for linear elastic response under such loading conditions, especially if, as a result of this design philosophy, no ductility capacity is provided in the system. This implies that the nonlinear behavior of yielding systems, which limits the seismic forces induced in structures, is a highly desirable feature.

[0003] For yielding systems, the energy dissipated per cycle through hysteretic yielding (inelastic deformations) is generally associated with structural damage. Such yielding systems are expected to sustain residual deformations which can greatly impair the structure and increase repair costs. This raises important questions which usually remain unanswered following extreme loading conditions: does a structure that has undergone a certain level

of inelastic deformation still provide the same level of protection as before? Must all yielded elements be replaced? Must the state of the material at every location where yielding has taken place be assessed?

[0004] There also exists a strong belief, mainly from the public, that a structure designed according to the latest seismic codes, for example, would require little or no structural repair and would result in minimal disruption time following an earthquake. Current research efforts in earthquake engineering still embrace this philosophy of achieving stable hysteretic response of predetermined elements of the structure. Structural damage and residual deformations are therefore expected under design level earthquakes.

[0005] Traditional steel braced frames are designed primarily to assure life safety under a major earthquake. They are expected to sustain significant damage after an earthquake due to repeated cycles of brace tension yielding and brace compression buckling. Furthermore, as a direct consequence of the damage induced in these elements, the final state of the entire building is likely to be out of plumb. Similar response is also expected from the other conventional structural systems (moment-resisting frames, walls, etc.). Poor structural performance also results in damage to operational and functional components of buildings, such as architectural components, building services or building contents. Both structural and non structural damage can impact on the safety and rescue of building occupants and can lead to interruption of building operations.

[0006] This reality has important consequences as to the costs of repair and the costs induced by disruption time following an important earthquake. Note that a structure that is found to be structurally sound after an earthquake may be condemned if the costs or straightening are elevated or if it appears unsafe to occupants. Increasingly, owners of structures in seismic

prone areas that are faced with the expected state of their structure following a major earthquake often opt to directly implement higher performance systems. Furthermore, insurance companies are also increasingly basing their premiums on expected damage costs, and with this additional incentive, the number of owners that will adopt high performance systems for new or existing structures is likely to increase.

[0007] The current state-of-the-art for specialized dampers that are used to improve seismic performance mainly consists of either hysteretic (yielding) or viscously damped systems. The hysteretic (yielding) systems consist of elements that are designed to undergo repeated inelastic deformations and that exhibit variable hysteretic responses.

[0008] A first family of such systems is referred to as yielding systems such as the buckling restrained braces or yielding steel plates. Yielding systems have been successfully implemented in numerous projects in Asia and North America. A second family of such systems is referred to as friction systems, of which one of the most popular is the Pall system. This system has been implemented in a very large number of structures in the past 15 years.

[0009] Note that none of these systems exhibits self-centering properties, which can negatively impact on the overall performance of structures when subjected to earthquakes and other extreme loads and results in permanent deformations.

[0010] Viscous systems are specialized devices that exhibit a velocity dependent force and increase the damping of the structure thus reducing the response under seismic loading. These devices are more expensive than the hysteretic type systems, and they do not assure self-

centering properties if the main structural elements undergo inelastic deformations.

[0011] To date, the hysteretic behavior has only been achieved by specialized dampers comprised of complex inter-connected spring elements that require sophisticated fabrication processes and shape memory alloy materials that are prohibitive in most common structural projects because of elevated costs.

[0012] The previous discussion leads to suggest that an optimal extreme load resistant system should:

[0013] i) incorporate the nonlinear characteristics of yielding structures to limit the induced forces;

[0014] ii) encompass re-centering properties allowing it to return to its original position after the extreme loading; and

[0015] iii) eliminate the damage to the main structural elements.

[0016] Optimal resistance to extreme loading increases the performance level of structures in the event of a major earthquake which sometimes occur in highly populated urban areas. Structures equipped with these high performance elements significantly offer better responses to such extreme loading with minimal damage, reduced repair costs and disruption time.

[0017] Furthermore, these systems may be very attractive to local, provincial and federal government facilities as well as to owners and managers

of critical facilities that must remain functional during and immediately after major catastrophic events.

OBJECTS OF THE INVENTION

[0018] An object of the present invention is therefore to provide an apparatus which encompasses the same architectural features as current technology and the same response characteristics under service loads, but offers a highly enhanced response under severe cyclic lateral loading: no structural damage and self-centering characteristics.

SUMMARY OF THE INVENTION

[0019] More specifically, in accordance with the present invention, there is provided an apparatus designed in the form of a bracing system that achieves a hysteretic behavior by combining specialized components that can be built using readily available construction materials.

[0020] The self-centering property of the apparatus generally includes post-tensioning elements along with a locking mechanism which connects the structural brace elements. This is achieved by combining structural elements and materials such as but not limited to structural steel and high-strength tensioning elements, bolts and welds.

[0021] In addition to the self-centering property, the apparatus relies on energy dissipating technology such as, but not limited to, friction surfaces, yielding sacrificial members, visco-elastic materials or viscous fluid dampers to provide the desired level of energy dissipation. All dissipative components, such as the frictional surface for a friction dissipative mechanism, that undergo deformations and dissipate input energy under extreme or repetitive loading

conditions, are generally positioned in such a way that they are accessible for inspection and, if needed, may be replaced following an extreme event.

[0022] Other objects, advantages and features of the present invention will become more apparent upon reading of the following non-restrictive description of preferred embodiments thereof, given by way of example only with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] In the appended drawings:

[0024] Figure 1 is a side elevation view showing the interior of a brace apparatus according to an embodiment of the present invention;

[0025] Figure 2 is a section view taken along line 2 in Figure 1;

[0026] Figure 3 is a section view taken along line 3 in Figure 1;

[0027] Figure 4a is a side elevation view showing the brace apparatus of Figure 1 in a generally unloaded condition;

[0028] Figure 4b is a side elevation view showing the brace apparatus of Figure 4a under a tension load that is sufficient to overcome the initial pre-tension;

[0029] Figure 4c is a side elevation view showing the brace apparatus of Figure 4a under a compression load that is sufficient to overcome the initial pre-tension;

[0030] Figure 5 is a schematic side elevation view showing main components of the proposed system with four possible dissipative mechanisms which may be used in the brace apparatus of Figure 1;

[0031] Figure 6 is a schematic view showing individual hysteretic responses of dissipative mechanisms which may be used in the brace apparatus of Figure 1;

[0032] Figure 7 is a schematic view showing combined hysteretic responses of dissipative mechanisms which may be used in the brace apparatus of Figure 1;

[0033] Figure 8 is a diagram view showing a typical hysteretic response for a yielding system;

[0034] Figure 9 is a diagram view showing a typical hysteretic response for a self-centering system;

[0035] Figure 10a is a schematic view showing the deformation of the different components of the brace apparatus of Figure 1, equipped with a friction or yielding energy dissipative mechanism, when under tension and before the tension force is large enough to overcome the initial pre-tensioning of the tensioning elements;

[0036] Figure 10b is a diagram of the hysteretic response of the system as shown in Figure 10a;

[0037] Figure 10c is a schematic view showing the deformation of the different components of the brace apparatus of Figure 1 equipped with a

friction or yielding energy dissipative mechanism, when under tension and when the tension force is larger than the force required to overcome the initial pre-tensioning of the tensioning elements;

[0038] Figure 10d is a diagram of the hysteretic response of the system as shown in Figure 10c;

[0039] Figure 11a is a schematic view showing the deformation of the different components of the brace apparatus of Figure 1 equipped with a friction or yielding energy dissipative mechanism, when under compression, and before the applied load is large enough to overcome the initial pre-tensioning effect on the structural elements of the brace apparatus;

[0040] Figure 11b is a diagram of the hysteretic response of the system as shown in Figure 11a;

[0041] Figure 11c is a schematic view showing the deformation of the different components of the brace apparatus of Figure 1 equipped with a friction or yielding energy dissipative mechanism when under compression and when the applied load is large enough to overcome the initial pre-tensioning effect on the structural elements of the brace apparatus;

[0042] Figure 11d is a diagram of the hysteretic response of the system as shown in Figure 11c;

[0043] Figure 12a is a schematic view showing the deformation of the different components of the brace apparatus of Figure 1 equipped with a viscous or visco-elastic energy dissipative mechanism when under tension and

before the applied load is large enough to overcome the initial pre-tensioning effect on the structural elements of the brace apparatus;

[0044] Figure 12b is a diagram of the hysteretic response of the system as shown in Figure 12a;

[0045] Figure 12c is a schematic view showing the deformation of the different components of the brace apparatus of Figure 1 equipped with a viscous or visco-elastic energy dissipative mechanism when under tension and when the applied load is large enough to overcome the initial pre-tensioning effect on the structural elements of the brace apparatus;

[0046] Figure 12d is a diagram of the hysteretic response of the system as shown in Figure 12c;

[0047] Figure 13a is a schematic view showing the deformation of the different components of the brace apparatus of Figure 1 equipped with a viscous or visco-elastic energy dissipative mechanism when under compression and before the applied load is large enough to overcome the initial pre-tensioning effect on the structural elements of the brace apparatus;

[0048] Figure 13b is a diagram of the hysteretic response of the system as shown in Figure 13a;

[0049] Figure 13c is a schematic view showing the deformation of the different components of the brace apparatus of Figure 1 equipped with a viscous or visco-elastic energy dissipative mechanism when under compression and when the applied load is large enough to overcome the initial pre-tensioning effect on the structural elements of the brace apparatus;

[0050] Figure 13d is a diagram of the hysteretic response of the system as shown in Figure 13c;

[0051] Figure 14 is a schematic side elevation view of a first structure incorporating the brace apparatus of Figure 1;

[0052] Figure 15 is a schematic side elevation view of a second structure incorporating the brace apparatus of Figure 1;

[0053] Figure 16 is a schematic side elevation view of a third structure incorporating the brace apparatus of Figure 1;

[0054] Figure 17 is a schematic side elevation view of a fourth structure incorporating the brace apparatus of Figure 1;

[0055] Figure 18 is a schematic side elevation view of a fifth structure incorporating the brace apparatus of Figure 1;

[0056] Figure 19 is a schematic side elevation view of a sixth structure incorporating the brace apparatus of Figure 1;

[0057] Figure 20 is a schematic side elevation view of a seventh structure incorporating the brace apparatus of Figure 1;

[0058] Figure 21 is a schematic side elevation view of an eighth structure incorporating the brace apparatus of Figure 1; and

[0059] Figure 22 is a schematic side elevation view of a ninth structure incorporating the brace apparatus of Figure 1.

DETAILED DESCRIPTION

[0060] Generally stated, the present invention relates to an energy dissipative brace apparatus which may be used to dissipate input energy and minimize or eliminate residual deformations related to an exceptional loading caused by winds, earthquakes, impacts or explosions which are imposed on structures or architectural systems.

[0061] As shown in one possible embodiment in Figure 1, the apparatus 30 generally includes at least a pair of generally parallel, structural bracing members 32, 34 which may be concentric and generally independently movable. The members 32, 34 are also generally longitudinally extending and may be bearing at their ends 36, 38, directly or through an intermediate shock absorbing mechanism (minimizing the impact), end plates 40a, 40b.

[0062] The members 32, 34 are made out of any material generally used for rigid structures or architectural constructions, such as, for example, steel. The material of the members 32, 34 is generally chosen to prevent or minimize the buckling or yielding occurrences and, thereby, to eliminate or not significantly induce damage to the structures where the members 32, 34 are attached or mounted to, such as brace connections or wall partitions.

[0063] The members 32, 34 may be made of circular, square or rectangular steel tubes inserted into one another. Other shapes can be used such as interconnected plates, I-shapes, C-shapes, etc.

[0064] The apparatus 30 also includes pre-tensioning elements (PT elements) 42, such as for example tendons bars or cables which may be made of, but not limited to, high strength steel tendons, rods, bars or of composite

FRP tendons or bars including, for example Aramid, Carbon, Glass or the like. Two or more elements 42 are generally used in the apparatus 30 to provide for redundancy and symmetry in the applied pre-tensioning. The elements 42 may also be pre-stretched up to the maximum expected deformation, prior to their installation, and then released to the desired initial tensioning force to provide an initial pre-tension as well as a re-centering capability. This initial pre-tensioning helps minimize default that could result in premature fracture of the PT elements and helps increase the reliability in the capacity of the PT elements. The elements 42 are mounted to and between end plates 40a and 40b.

[0065] The elements 42 are generally capable of deforming to meet a target brace elongation without any yielding and without any loss of the initial pre-tensioning force. The number of elements or their total area controls the post-yield stiffness of the system. For instance, Aramid fiber tendons have above 3% elongation capability.

[0066] As seen in Figure 1, the members 32, 34 may include specially designed end connections 44a and 44b, or an additional structural steel element generally mounted in series to the apparatus 30, that may be designed to yield prior to attaining the ultimate capacity of the elements 42, and thus minimizes the possibilities of the elements 42 failing in the event of unexpectedly higher deformations. The end connection 44a is rigidly attached (welds, bolted or joined assemblies) to the internal member 32 such that the relative movement of the member 32 is generally not restrained by the end connection 44a with respect to the end plate 40a.

[0067] As seen in Figure 1, end connection 44a may be slidable through a channel or slot (not shown) in end plate 40a. Similarly, the end connection 44b is rigidly attached (welds, bolted or joined assemblies) to the

external member 34. As can be seen from Figure 1, both end plates 40a, 40b rest against opposite ends of the external member 34, due to the pre-tensioned elements 42, when the system is in an unloaded state.

[0068] If all elements 42 of the apparatus 30 brake when unexpectedly solicited, the apparatus 30 can still work as a friction, yielding, viscous or visco-elastic damper with energy dissipation capacity.

[0069] Energy dissipative capacities in the apparatus 30 may be provided by any combinations of friction 46, yielding 48, viscous 49 and/or visco-elastic 50 mechanisms or components that are mobilized or involved when relative longitudinal movement develops between the two members 32, 34. These mechanisms are illustrated in Figures 1 to 5 and 10a to 13d.

[0070] The energy dissipative mechanisms are generally chosen to either sustain minimal damage under severe loading, or to be easily replaceable. Also, all dissipative mechanisms are generally designed within the apparatus to allow quick inspection and replacement with minimal disruption time following any extreme loading situation.

[0071] Friction energy dissipative mechanism 46 may be used individually in the apparatus 30, but all energy dissipative mechanisms systems 46, 48, 49, 50 may also be included, individually or in combination, in the apparatus 30 such that their properties can be tuned to achieve the desired response.

[0072] A friction energy dissipative mechanism 46 (illustrated in Figures 1 and 2) may be used to obtain energy dissipative capacity by inserting a frictional interface 52 including friction elements 52d, 52e between supports

52a, 52b mounted to the movable members 32, 34 and by applying a normal force clamping the friction elements 52d, 52e together by means of pre-tensioned bolts or other appropriate methods. This may also be achieved by directly clamping together the supports 52a, 52b and a plate 52c without the friction elements 52d, 52e or any other elements. The friction energy dissipative mechanism 46 generally displays stable hysteretic characteristics under dynamic loading, with minimal uncertainty on initial and long-term friction properties. Specialized, non-metallic friction interfaces (not shown), or treated metallic surfaces (not shown) can also be used to provide specific hysteretic characteristics to the friction dissipative mechanism.

[0073] In the embodiment shown in Figures 1 and 2, the interface 52 includes supports 52a, 52b fixedly mounted on the external member 34. The supports 52a, 52b hold the spacers 52d, 52e and a friction plate 52c in a clamping arrangement such that the friction plate 52c is in contact with the member 32. The interface 52 may include a sliding arrangement of at least one slot 53 and at least one sliding member 51 to allow the relative movement between the members 32, 34 which may be subjected to opposite forces and to allow the movement of the friction plate 52c. The slot 53 may be positioned on the supports 52a, 52b or on the spacers 52d, 52e.

[0074] Yielding energy dissipative mechanism (48 or Y in Figure 5) may be used to obtain energy dissipative capacity by inserting between and connecting to the two movable members 32, 34 metallic elements (not shown) that may yield under axial, shear or flexural deformations, or a combination thereof.

[0075] Viscous (49 or V) or Visco-Elastic (50 or VE) energy dissipative mechanism may be used to obtain energy dissipative capacity by inserting between and connecting to the two movable members 32, 34 devices

(not shown) containing viscous fluids or plates connected to visco-elastic material.

[0076] Combinations of more than one of the above energy dissipative mechanisms can be used to optimize and diversify the hysteretic characteristics of the apparatus 30.

[0077] Guiding elements 58 such as plates, blocks, or other elements may also be provided between the members 32, 34 to allow, guide or impose movement and/or force transfer to the members 32, 34 and to maintain their relative alignment. Absorbing materials (not shown) may also be used to mitigate impact between the members 32, 34. Also, additional guiding elements 70 may be used to connect or mount the elements 42 to the members 32, 34, along the length of these members 32, 34, to enhance the buckling capacity of members 32, 34.

[0078] The apparatus 30 therefore generally combines a post-tensioning system as well as a variety of possible energy dissipative components, such as friction (FR or 46), yielding (Y or 48), visco-elastic (VE or 50) and viscous (V or 49) mechanisms to create a structural brace element exhibiting a "Flag-Shaped Hysteresis" which combines energy dissipative and full self-centering capabilities.

[0079] The combination of post-tensioning elements and a source of energy dissipative, along with a locking mechanism generally allow the aforementioned hysteresis to be developed simply by combining structural elements and materials such as, for example, structural steel and high-strength tensioning elements.

[0080] The locking mechanism involves the end plates 40a and 40b, the elements 42 and the members 32, 34 and is schematically illustrated in Figures 5 and 10a to 13d. The effect of the locking mechanism when external tension or compression loads are applied to the apparatus 30 is to induce a relative motion between the two structural bracing members 32, 34, which results in the elongation of the pre-tensioning elements 42 that are connected to the end plates 40.

[0081] The locking mechanism allows for this elongation of the pre-tensioning elements 42 to occur symmetrically when both tension and compression are applied to the apparatus (applied at 44). The elongation of the pre-tensioning elements 42 generates the spring force that assures the self-centering property of the system.

[0082] Figure 5 schematically illustrates the apparatus 30 which includes the two members 32, 34 that may be inserted into each other or located one next to the other and connected to locking end plates 40a, 40b at both ends 36, 38. An opening (not shown) may be provided in the external member 34 to allow for the connection of dissipative elements (FR, Y, V, and or VE) that are activated by the relative motion of these two members 32, 34. The two locking end plates 40a and 40b are pre-tensioned with high strength tensioning elements 42.

[0083] The dissipative elements (FR, Y, V, and or VE) are generally activated by the relative motion between the two members 32, 34. The elements 42 are also further extended by the relative motion of the two members 32, 34, thus creating the necessary restoring force to bring the apparatus 30 back to its initial position after the loading.

[0084] For instance, when tension is applied to the apparatus 30, and once the initial force and resistance of the dissipative mechanism are overcome, the apparatus 30 elongates resulting in an increase of the force while energy is dissipated through the dissipative mechanisms. If the elements 42 are chosen correctly relative to the resistance of the dissipative mechanisms 46, 48, 49, 50, the restoring force from the further extended elements 42 brings the apparatus 30 back to its initial position when the load is released.

[0085] The hysteretic characteristics of the proposed system can be obtained by adding the contribution from each of the pre-tensioning elements and of the dissipative mechanisms. Figure 6 illustrates the individual contributions of four primary dissipative mechanisms, friction, yielding, viscous and visco-elastic, and Figure 7 illustrates some combinations of different dissipative mechanisms.

[0086] Even if only two different dissipative elements are shown in Figure 7, a combination of more than two dissipative systems of the same type, or combinations of more than two types of dissipative elements may also be used. Other combinations may also exist such as three different dissipative systems or more than one energy dissipative element of the same type used in combination with another different energy dissipative elements.

[0087] When compression is applied to the brace, a similar hysteretic behavior is observed because of the locking mechanism that is present. When the load is once again reversed, once the apparatus 30 is straightened, the previously described hysteretic behavior in tension is repeated.

[0088] The total hysteretic response of the system can be obtained by summing the contributions from the various components described herein

and the dissipative mechanisms. Four dissipative mechanisms are illustrated in Figure 6, and the hysteretic behaviors are schematically shown for two families of apparatuses 30 with combined dissipative mechanisms in Figure 7.

[0089] In Figure 8 and 9, the force displacement curve of a typical linear elastic system and of a typical self-centering system representing a yielding structure of equal initial stiffness and mass is schematically shown. The shaded area represents the energy dissipated per cycle through hysteretic yielding, which is generally associated with structural damage.

[0090] Furthermore, as illustrated in Figure 8, typical yielding systems are expected to sustain residual deformations which can greatly impair the structure and increase repair costs. The self-centering capacity incorporated in the apparatus 30 offers a hysteretic behavior which is optimized (diagrammatically shown in Figure 9) having regards to the response and the residual deformation.

[0091] The mechanism principle for the embodiment of Figure 1 is illustrated in Figures 4a to 4c. Figure 4a shows the brace apparatus 30 when it is not subjected to any external loading.

[0092] When a first loading force F tensions the apparatus 30 (see Figure 4b) such that the pre-tensioning of the elements 42 are overcome, the elements 42 start stretching or elongating and the members 32, 34 start moving apart. As seen in Figure 4b, the end plate 40a, the end connection 44a and the member 34 are moved away from the other member 32 which stays in contact with the other end plate 40b and therefore tensions the pre-tensioned elements 42. One skilled in the art will readily understand that should the force F be removed, the apparatus 30 would come back to its unloaded configuration shown in Figure 4A.

[0093] On the other hand, when a second loading force F compresses the apparatus 30 such that the pre-tensioning of the elements 42 is overcome, the elements 42 start stretching or elongating and the members 32, 34 start moving apart. As seen in Figure 4c, the end plate 40b, the end connection 44a and the member 34 are moved away from the other member 32 which stays in contact with the other end plate 40a and therefore tensions the pre-tensioned elements 42. One skilled in the art will readily understand that should the force F be removed, the apparatus 30 would come back to its unloaded configuration shown in Figure 4A.

[0094] Another example showing the mechanism principle is shown in Figures 10a to 11d which show the hysteretic behavior of the apparatus when a displacement activated mechanism such as friction or yielding is used. In Figures 12a to 13d, the hysteretic behavior of the apparatus 30 involves the use of a velocity-dependent mechanism, such as viscous or visco-elastic.

[0095] In all these figures, the elongation of the apparatus 30 under load F is expressed as δ while δ' illustrates the deformation in the dissipative mechanisms connected to the two members 32, 34. In Figures 12a to 13d, both a low velocity and high velocity response are illustrated since the dissipative elements display a velocity dependent hysteresis. The high velocity response is generally expected during the extreme loading, while the low velocity response (which generally assures the self-centering property) characterizes the expected response following the extreme loading.

[0096] The relative movements of the various components of the apparatus 30 will be further explained with Figures 10a to 11d, but the same principle applies to other combinations of different dissipative mechanism (as the configuration shown in the Figures 12a to 13d) and of various member configurations as described hereinabove.

[0097] The effect of the locking mechanism is schematically shown in Figures 10c and 12c for the case where tension is applied to the system and in Figures 11c and 13c for the case where compression is applied to the system.

[0098] Figure 10a shows the deformation of the different components of the brace apparatus 30 which is equipped with a friction or yielding energy dissipative mechanism, under tension and before the applied (or external) tension force is large enough to overcome the initial pre-tensioning.

[0099] Up to a certain level, a force F tensions the members 32, 34 as shown in Figure 10a, such that the dissipative mechanism 46 prevents the members 32, 34 from moving relative to each other. At that stage however, generally linear elastic deformation in the members 32, 34 may occur, as shown in Figure 10b.

[0100] Figure 10c is a schematic view showing the deformation of the different components of the brace apparatus of Figure 1 equipped with a friction or yielding energy dissipative mechanism, when under tension, and when the applied tension force is larger than the force required to overcome the initial pre-tensioning. When the force F reaches the separation level (61 in Figures 10b and 10d) and overcomes the elements 42, the members 32, 34 start moving in opposite directions by a distance δ. The pre-tensioned elements 42 mounted to both members 32, 34 are therefore elongated by a generally similar displacement and may deform under such loading. The dissipative mechanism 46 also deforms by a displacement δ'.

[0101] Once the loading changes its direction such as it usually does in an oscillatory earthquake loading, the opposite force F shown in Figure

11a pushes the apparatus 30 back to its original position (opposite and equal displacement δ), with the two members 32, 34 generally aligned and with the dissipative mechanism 46 back near to its initial position. If no force F is provided after a first loading F in an opposite direction, the elements 42 generally reposition the members 32, 34 to the state shown in Figure 11a. This phenomenon may be explained by a spring-like force coming from the pre-tensioned and further stretched condition of the elements 42.

[0102] As seen in Figure 11b, the hysteretic response of the dissipative mechanism 46 goes to the tensioned side of the force F to the compression side of the force F by passing generally near the zero force-displacement point in the diagram. In the case where no opposite compressive force F is provided, the spring like force of the elements 42 put the system to rest, to the zero force-displacement point in the diagram.

[0103] Once the opposite force F reaches a certain level, the separation level (63 in Figures 11b and 11d) is attained such that the dissipative mechanism 46 is overcome and such that the members 32, 34 start moving in opposite directions by a distance δ. The dissipative mechanism 46 may then deform by a corresponding displacement δ'.

[0104] The relative movements of the components described hereinabove may alternate until the critical point of the system is reached due to intense loads which are larger than the anticipated loads for which the apparatus 30 has been designed to withstand.

[0105] The apparatus 30 may be used by being mounted on, connected to or integrated in various types of structures 60, some being shown in Figures 14 to 22.

[0106] The apparatus 30 may be used for new constructions which would be built with traditional lateral load resisting systems (conventional braced frames, moment-resisting frames, shear walls, etc.) or with added dampers that do not exhibit the highly desirable self-centering property. These structures could be built with the proposed apparatus to enhance their seismic performance level.

[0107] The apparatus 30 may also be used in the existing market of existing constructions which need to be laterally strengthened or rehabilitated to meet more recent (more stringent) seismic code provisions or higher performance criteria. Rehabilitation of these structures could be done using traditional structural techniques (by adding or strengthening conventional braced frames, moment-resisting frames, shear walls, etc.) or by the addition of dampers or other energy dissipative devices from the prior art which do not exhibit the highly desirable self-centering property. These structures could also be rehabilitated using the proposed apparatus 30 for enhanced seismic response.

[0108] The apparatus 30 may also be used in important structures which need to be protected from extreme blast loads because the apparatus 30 may offer the self-centering property that is not offered by devices from the prior art.

[0109] The apparatus can be used in various structures such as buildings, towers, bridges, offshore platforms, storage tanks, etc (some possible applications are illustrated in Figs 14-22). The apparatus can be installed at an angle between framing members in a structure, vertically or horizontally at the base of structures, or generally in parallel with any movement within the structure that may necessitate control.

[0110] Figures 14-22 show typical Civil Engineering applications. Furthermore, the system can also be used in other applications such as in mechanical engineering for vehicles subjected to impact, equipment or machinery that can be subjected to overloading or unanticipated loading conditions, etc.

[0111] The fabrication of the apparatus 30, its inter-connections and its connections to existing structures needing bracing involve simple steps and can be made and installed by regular construction workers. The apparatus is generally entirely self-contained.

[0112] Once assembled in the production factory, the apparatus 30 is then attached or mounted to the structures in a similar way as traditional bracing elements are generally attached, by bolting or welding of end connection plates (44 in Figures 1 and 5) to the main structure (60 in Figures 10a, 10c, 11a, 11c, 12a, 12c, 13a and 13c).

[0113] Although the present invention has been described hereinabove by way of preferred embodiments thereof, it can be modified, without departing from the spirit and nature of the subject invention as defined in the appended claims.

ABSTRACT OF THE DISCLOSURE

The present invention generally relates to a self-centering energy dissipative brace apparatus. A bracing system is often needed to stabilize, strengthen or stiffen structures such as buildings which are subjected to extreme conditions. The brace apparatus may be installed in a structure to dissipate input energy and minimize residual deformations related to exceptional loading imposed on the structure by winds, earthquakes, impacts or explosions. The apparatus integrates self-centering properties and energy dissipative capacities which help minimize structural damages.

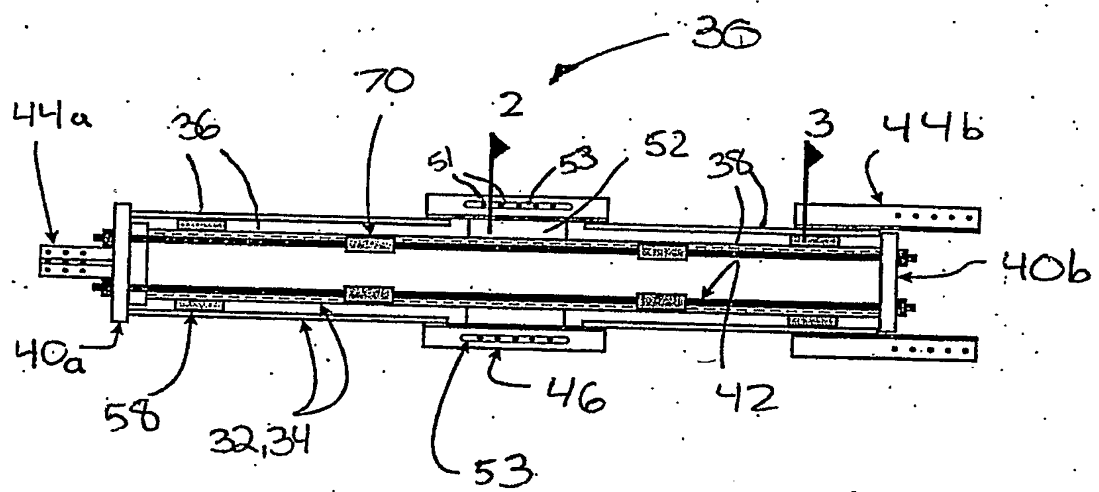

FIGURE 1

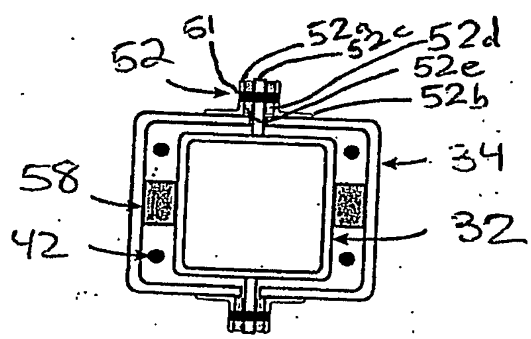

FIGURE 2

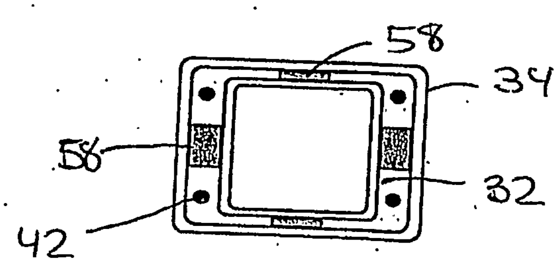

FIGURE 3

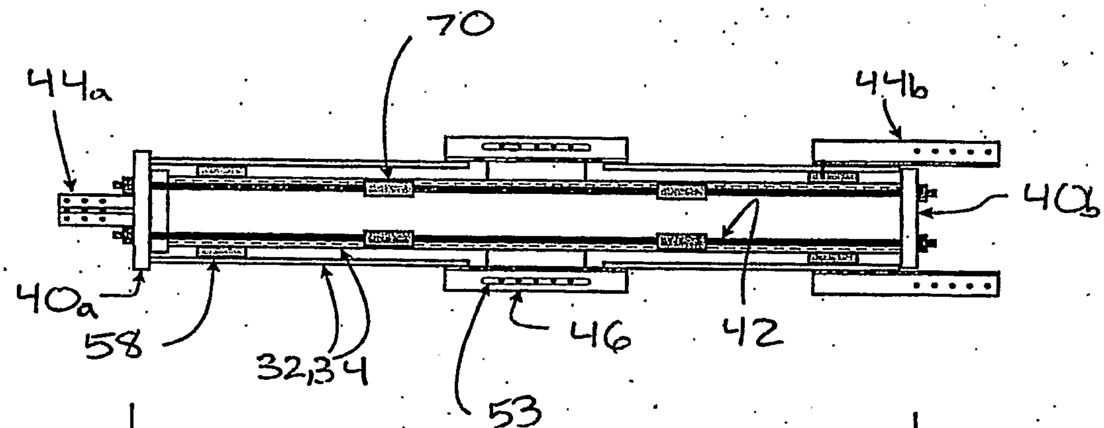

FIGURE 4A

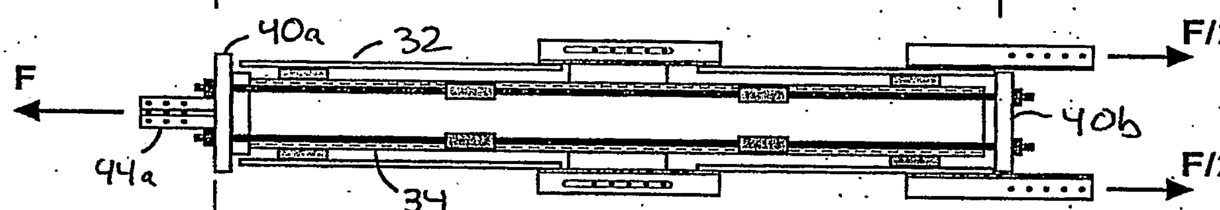

FIGURE 4B

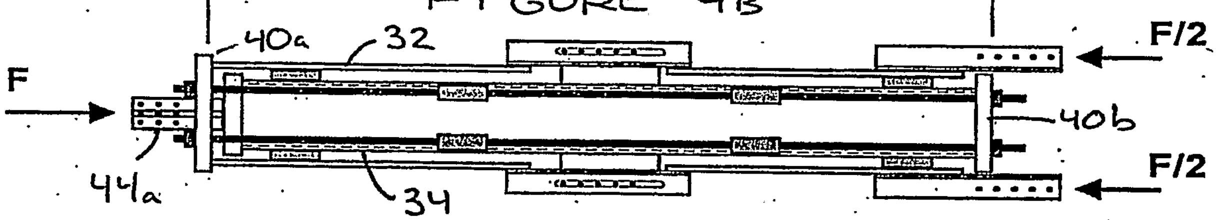

FIGURE 4C

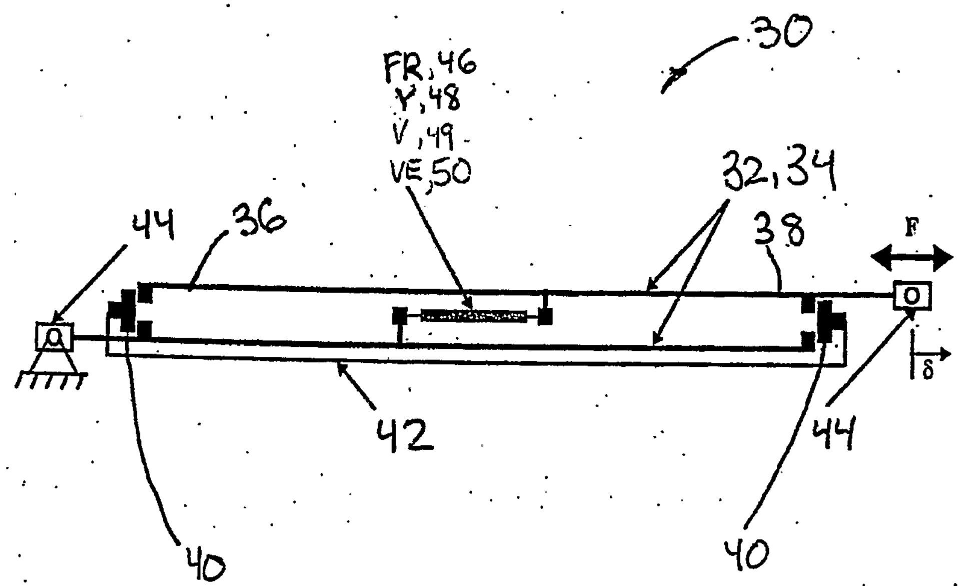

FIGURE 5

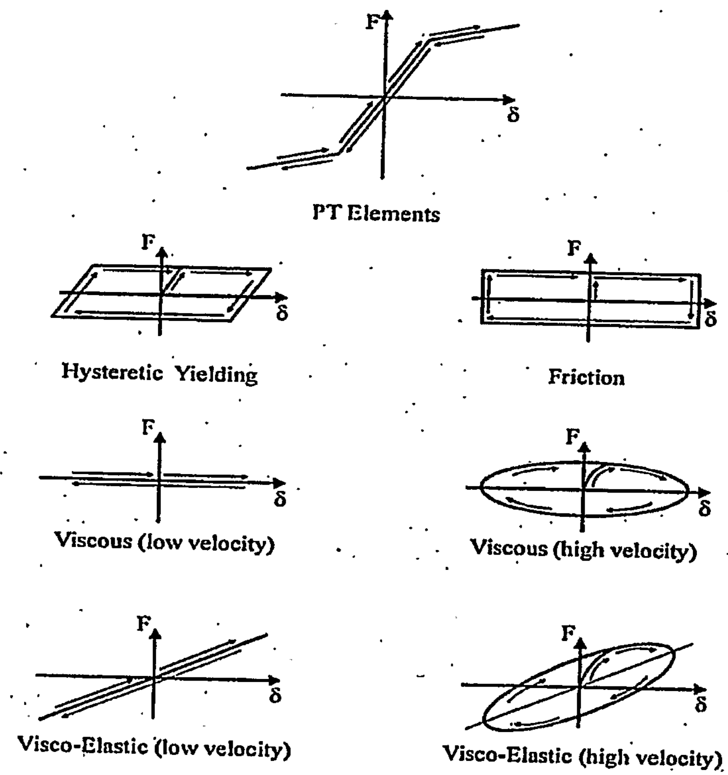
F
δ
PT Elements
F
δ
Hysteretic Yielding
F
δ
Friction
F
δ
Viscous (low velocity)
F
δ
Viscous (high velocity)
F
δ
Visco-Elastic (low velocity)
F
δ
Visco-Elastic (high velocity)

FIGURE 6

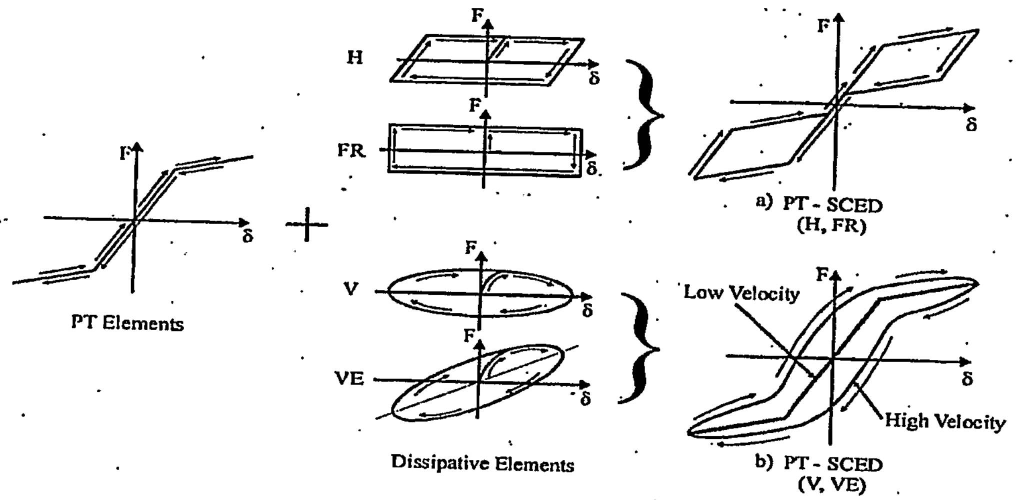

FIGURE 7

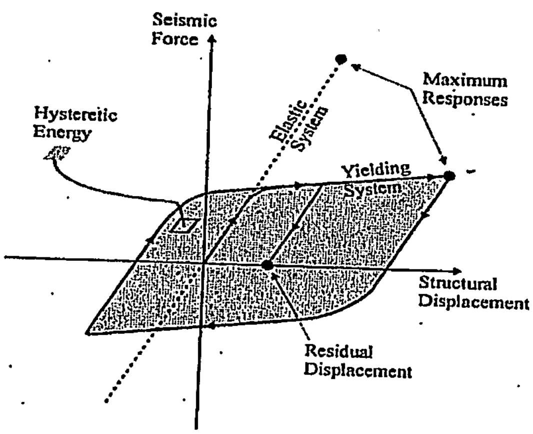

FIGURE 8

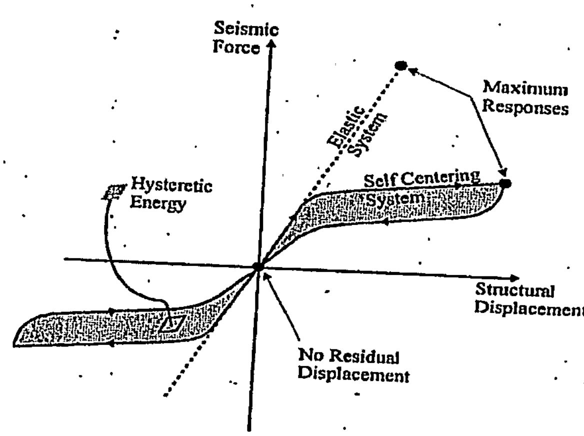

FIGURE 9

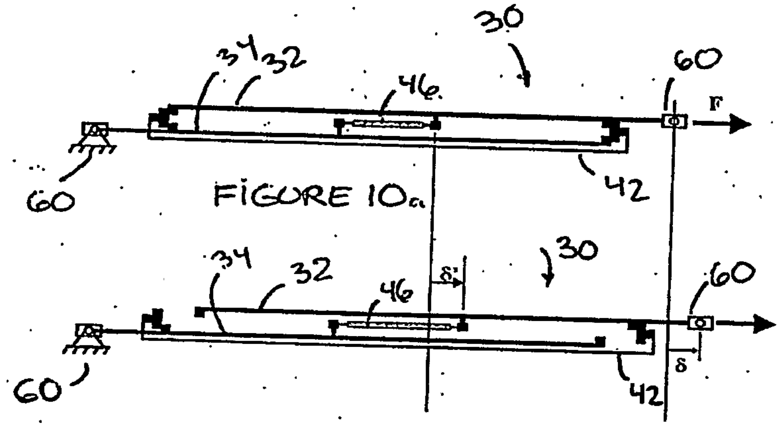

FIGURE 10a

FIGURE 10c

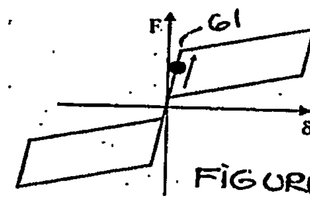

FIGURE 10b

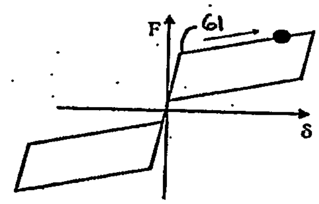

FIGURE 10d

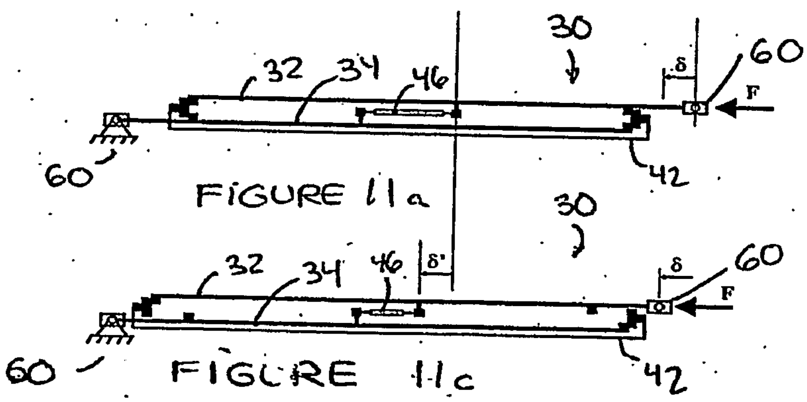

FIGURE 11a

FIGURE 11c

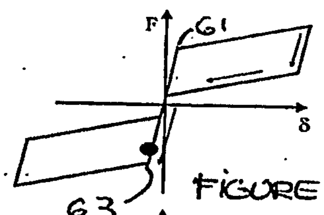

FIGURE 11b

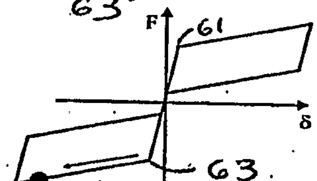

FIGURE 11d

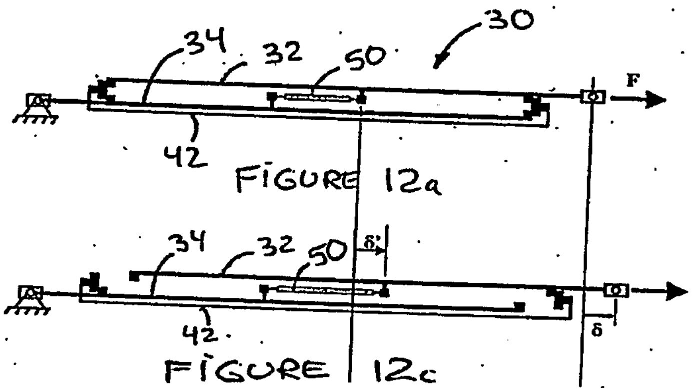

FIGURE 12a

FIGURE 12c

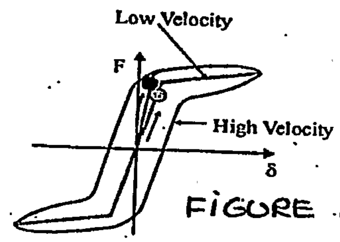

FIGURE 12b

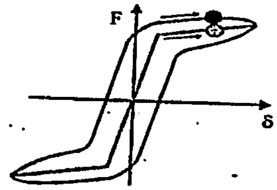

FIGURE 12d

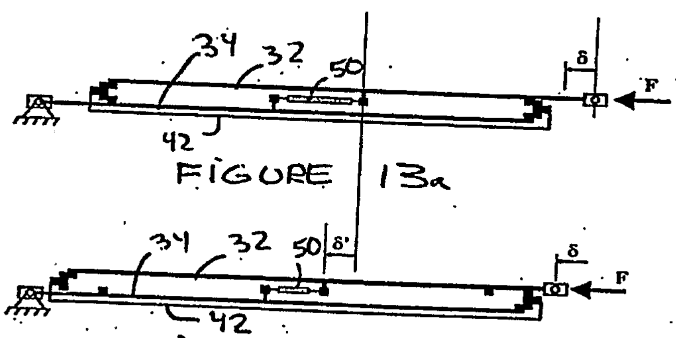

FIGURE 13a

FIGURE 13c

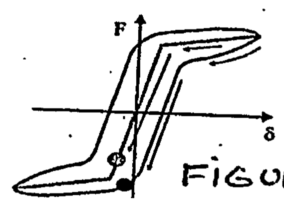

FIGURE 13b

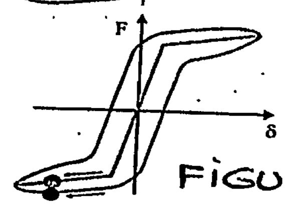

FIGURE 13d

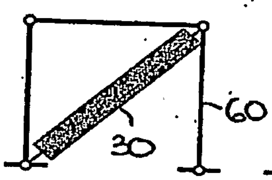

FIGURE 14

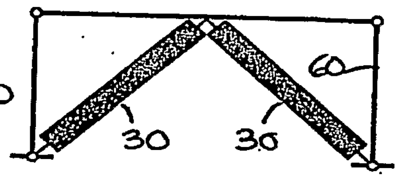

FIGURE 15

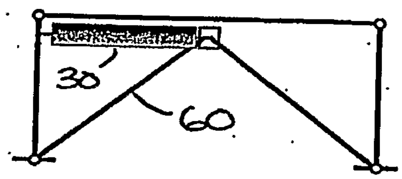

FIGURE 16

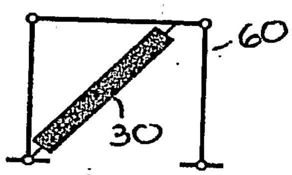

FIGURE 17

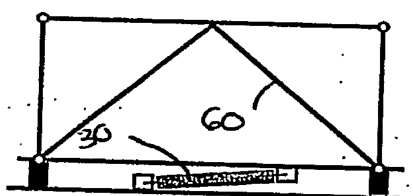

FIGURE 18

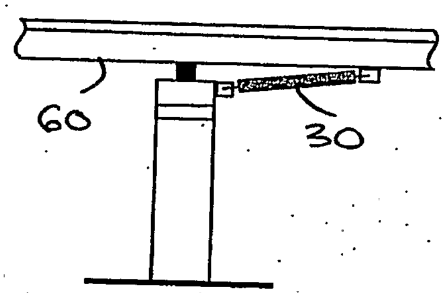

FIGURE 19

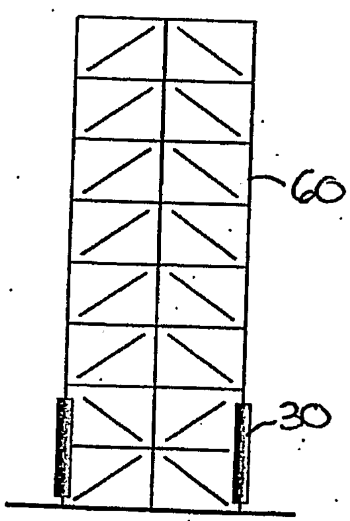

FIGURE 20

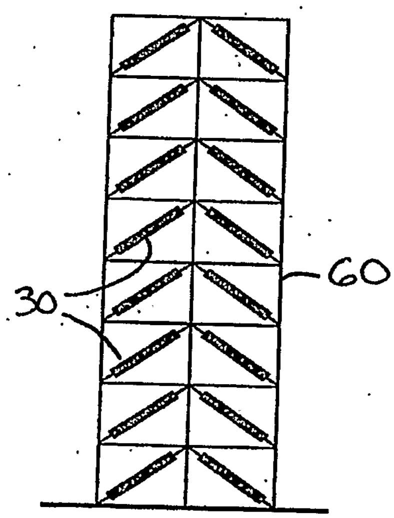

FIGURE 21

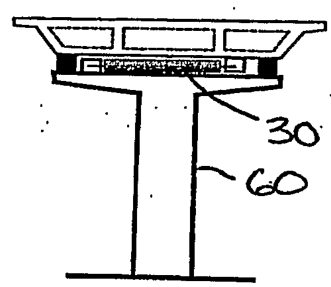

FIGURE 22